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Halosulfuron Has a Variable Effect on Cucurbit Growth and Yield

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Abstract. **Halosulfuron is a proposed alternative to methyl bromide for managing nutsedges (*Cyperus* spp.) in several vegetable crops, including cucurbits. Field studies were conducted to evaluate the crop sensitivity to halosulfuron in a spring squash (*Cucurbita pepo* L.)—fall cucumber (*Cucumis sativus* L.) rotation from 2000 to 2002. Treatments included application of halosulfuron to the soil surface after forming the bed, but before laying mulch (halosulfuron-PRE), halosulfuron applied through drip irrigation (halosulfuron-DRIP) after forming bed and laying mulch, metham applied through drip irrigation after forming bed and laying mulch, a nontreated control with mulch, and nontreated control without mulch. Each treatment was applied to both direct seeded and transplanted zucchini squash. Halosulfuron treatments reduced squash plant diameter relative to metham, however plant diameters in halosulfuron-PRE (transplant and direct seed) and halosulfuron-DRIP (transplant) treatments were not different from the nontreated control. Halosulfuron-PRE delayed squash fruit production relative to the mulched nontreated control. However, application of halosulfuron-PRE and halosulfuron-DRIP did not reduce squash yield at the conclusion of the season, relative to the nontreated control. Cucumbers were transplanted and direct seeded into previous squash plots and received either an application of halosulfuron-DRIP, or were not treated. Differences in cucumber yields were not detected with second crop treatments. Cucumbers appear to have adequate tolerance to halosulfuron, making it a potential replacement for methyl bromide for nutsedge control. Suppression of early season squash growth by halosulfuron may hinder the adoption of halosulfuron as a methyl bromide alternative for squash.**

Yellow and purple nutsedge are among the most troublesome vegetable weeds in Georgia and the southern U.S. (Webster, 2002; Webster and MacDonald, 2001). The impending elimination of methyl bromide will soon leave vegetable growers without a valuable tool for pest management, with limited options for suppression of nutsedge growth (Harrison and Fery, 1998). Halosulfuron (Sandea; Gowan Company, Yuma, Ariz.) has been identified as a potential herbicide for use in several cucurbit crops (Batts et al., 2001; Brown and Masiunas, 2002; Haar et al., 2002; Johnson and Mullinix, 2002). Halosulfuron, applied in a number of crops controlled yellow and purple nutsedge (Blum et al., 2000; Derr et al., 1996; Vencill et al., 1995), impeded tuber production (Lowe et al., 2000; Nelson and Renner, 2002; Warren and Coble, 1999), and reduced tuber viability (Molin et al., 1999). Previous studies with cucurbits indicated that certain species and cultivars within a species had greater sensitivities than others (Buker and Stall, 2001; Stall and Majek, 1995; Webster et al., 2003), and application method affected crop injury (Garvey et al., 1997; Mitchem and Monks, 1997).

To minimize inputs, growers have opted to leave mulched beds in place for multiple crops. This can increase the difficulty in managing pests, as many of the fumigant treatments (including methyl bromide) require application before installation of polyethylene mulch. Previous studies have indicated that metham and 1,3-dichloropropene can be successfully applied through drip irrigation, providing management options for specific pests in existing beds that will be re-cropped (Ajwa et al., 2002; Csinos et al., 2002; Webster et al., 2001). However, application of herbicides (nonfumigants) through drip irrigation has not been previously reported. The option of halosulfuron application through the drip irrigation could be a beneficial means of controlling nutsedge at establishment of the mulched bed, as well as in second and third crop use of the mulched bed. The objective of this field study was to evaluate the effect of halosulfuron, applied to the soil surface and through the drip irrigation, on zucchini squash and cucumber growth and yield in a plasticulture system.

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Materials and Methods

Field studies were conducted in Tifton, Ga., at the Blackshank Farm in 2000 and at the Jones Farm in 2001 and 2002. The soil type in 2000 was a Dothan loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) consisting of 86.8% sand, 9.6% silt, 3.6% clay (Perkins et al., 1986; Soil Survey Division, 2001) with 0.8% organic matter and pH 6.0. In 2001 and 2002 the soil type was a Tifton loamy sand (Fine-loamy, kaolinitic, thermic Plinthic Kandiudults) consisting of 86.5% sand, 7.0% silt, 6.5% clay (Soil Survey Division, 2001) with 0.8 to 1.0% OM and pH of 6.3 to 6.5. Raised beds (15 cm tall) were formed in one operation (Blue Line Superbedder 4000; Kennco Mfg., Inc.) and polyethylene mulch and drip tape applied in a separate operation (Blue Line Plastic Mulch Layer 3000; Kennco Mfg., Inc.). Black low-density polyethylene mulch (thickness of 32 μm) and drip tape (T-Tape: output of 250 $L \cdot h^{-1}$ per 100 m at 0.55 Bar, tubing wall 0.2 mm thick, emitters spaced 20 cm apart) were laid in plots (1.8 × 6.1 m), with a bed top of 0.76 m. Treatments were arranged as a randomized complete block design with four replications. Each bed was treated with Inline, a mixture of 133 $kg \cdot ha^{-1}$ a.i. 1,3-dichloropropene and 73 $kg \cdot ha^{-1}$ a.i. chloropicrin, injected through the drip irrigation system (1500 ppm injected over 6 h, followed by flushing of the lines for 1 h) 17 to 20 d before planting. The test was managed uniformly for fertility and pests following University of Georgia Extension recommendations (Boyhan et al. 1999). At planting, all plots received an application of 168 $kg \cdot ha^{-1}$ of 10N–16P–0K through drip irrigation. Throughout the growing season, plots were watered 3 to 5 times a week (based on need) and each week received 22 $kg \cdot ha^{-1}$ of 7N–0P–5.8K liquid fertilizer injected through the drip irrigation system.

The study was a split-split plot design with main plots as nutsedge management treatment applied to squash (first crop), subplots as squash and cucumber planting method (direct seeded or transplanted), and sub-subplots as treatment before cucumber (second crop). Main plot treatments included 1) metham (sodium salt formulation) applied through the drip irrigation at 145 $kg \cdot ha^{-1}$ a.i. (maximum registered use rate) following mulch laying; 2) halosulfuron at 39 $g \cdot ha^{-1}$ a.i. applied preemerence to the soil surface after forming the bed, but immediately before mulch laying (halosulfuron-PRE); 3) halosulfuron at 39 $g \cdot ha^{-1}$ a.i. applied through the drip irrigation following mulch laying (halosulfuron-DRIP); 4) nontreated control with mulch, and 5) nontreated control without mulch (bare ground). Metham was mixed with 3.8 L of water and injected into the drip irrigation system for 30 min using a pump that delivered 126 mL·min^{-1}. Following treatment, the irrigation lines were flushed with water for 1 h. Metham was applied 25 Apr. 2000, 19 Apr. 2001, and 1 Apr. 2002. Halosulfuron-PRE was applied with a tractor-mounted CO_2-pressurized sprayer calibrated to deliver 187 L·ha^{-1} at 150 kPa at 4.8 km·h^{-1} on 25 Apr. 2000, 19 Apr. 2001, and 1 Apr. 2002. Halosulfuron-DRIP was mixed with 2.1 L of water and injected into the drip irrigation system over a 1 h time period using a pump that delivered 35 mL·min^{-1}. Halosulfuron-DRIP was applied 25 Apr. 2000, 19 Apr. 2001, and 5 Apr. 2002.

'Spineless Beauty' zucchini squash was transplanted or direct seeded on 15 May 2000, 3 May 2001, and 10 Apr. 2002. Due to excessive rainfall within 2 d of transplanting in 2002, there was significant crop mortality of transplanted squash; squash were retransplanted 9 May 2002. Direct-seed squash were unaffected by the rainfall in 2002. 'Speedway' cucumber was direct seeded or transplanted 24 Aug. 2000, 30 Aug. 2001, and 15 Aug. 2002. Sub-subplot treatments included either application of 39 g·ha^{-1} halosulfuron through the drip irrigation (as previously described) or no treatment. Halosulfuron applications (sub-sub plot) were made 18 Aug. 2000, 28 Aug. 2001, and 12 Aug. 2002. All plots were treated with 0.84 kg·ha^{-1} a.i. glyphosate between the first and second crop, with >1.3 cm of rainfall or irrigation occurring between application and planting of the second crop. Transplants of squash and cucumber were grown in the greenhouse using previously described methods (Webster et al., 2001).

A visual rating of crop injury was made at 21 d after planting (DAP) using a scale of 0 (no crop injury) to 100 (plant death). Diameters of four squash and cucumber plants per plot were measured at 30 to 32 DAP. Squash and cucumber were hand-harvested between 5 and 14 times and 3 and 6 times, respectively, depending upon crop conditions. In each year, squash plants began to decline by 65 d after planting/transplanting. The number of cucumber harvests was a function of cool temperatures in autumn. Yield data were grouped and analyzed in three categories to evaluate 1) the effect of treatments in delaying fruit maturity (initial harvest and second harvest), 2) recovery of the plant from early-season treatment-related injury (final harvest), and 3) overall effect of treatments on fruiting (cumulative crop yield). For each harvest, fruit biomass data were transformed as a percent of the mulched nontreated control. Data were analyzed using analysis of variance. Treatment means were separated using Fisher's protected $LSD_{0.05}$.

Results and Discussion

Zucchini squash growth. Early in the growing season, squash plants treated with halosulfuron were lighter yellow in color relative to the dark green plants in the metham and nontreated plots. Injured squash plants were also stunted, with smaller leaves and shorter internodes than the nontreated plots, but with normal-sized petioles that appeared out-of-proportion on the stunted plant. The similarity in crop injury response to treatments in 2000, 2001, and 2002 transplant allowed for data to be combined for these planting method-year groupings. A visual rating of crop injury at 21 DAP indicated ≤13% injury from all treatments, though halosulfuron treatments had greater injury than the nontreated control (Table 1). Crop injury from halosulfuron treatments in 2002 direct seed was more severe than in other planting method years. Halosulfuron injured direct seed-squash 25% to 38% in 2002, greater than all other treatments. Greater injury from halosulfuron-DRIP in 2002 may have occurred due to the shortened interval between application of halosulfuron and squash planting in 2002 (7 d) compared to 2000 and 2001 (16 to 21 d). However, halosulfuron-PRE applied 21 to 23 d before transplanting or seeding in 2000 and 2001 caused 11% crop injury, while application 27 d before transplanting or seeding in 2002 caused 25% injury. In spite of the earlier planting date in 2002 (relative to 2000 and 2001), accumulated growing degree-days (T_{base} = 10 °C) after planting were similar among the years (Fig. 1). Growing degree-days in 2001 and 2002 were similar during the first 40 d after planting or transplanting. Therefore, temperature was not likely a factor contributing to increased crop injury due to halosulfuron in 2002.

A significant portion of the visual injury observed from halosulfuron was manifested as a reduction in plant size (i.e., smaller plant diameters). Squash plant diameters at 30 to 32 DAP in halosulfuron treatments were similar to the nontreated control in all years, indicating rapid crop recovery from initial injury (Table 1). Previous research on watermelon has demonstrated rapid recovery from early season crop injury (Culpepper et al., 2001). Squash treated with metham had larger plant diameters than all other treatments, though the reason for this is not clear. Nematodes were not found on the squash roots and weed populations were low and not different among treatments (data not shown). Suppression of other soilborne plant pathogens by metham may have contributed to the increase in crop yield.

Zucchini squash yield. In spite of dif-

Table 1. The effect of weed management treatments on squash growth evaluated in terms of plant diameter.

Treatment	Crop injury (%) at 21 DAP[v] 2000–02 (transplanted)	Crop injury (%) at 21 DAP[v] 2002 (direct seed)	Crop diam (% of nontreated control) (30 to 35 DAP)
Halosulfuron-DRIP[z]	11	38	93
Halosulfuron-PRE[y]	13	25	92
Metham[x]	4	9	113
Mulched nontreated control[w]	0	0	90
Nonmulched nontreated control[w]	0	0	100
$LSD_{0.05}$	9	15	11

[z]Halosulfuron applied at 39 g·ha^{-1} through drip irrigation before crop transplant.
[y]Halosulfuron applied at 39 g·ha^{-1} to the soil surface immediately before laying polyethylene mulch.
[x]Metham applied at 145 kg·ha^{-1} through drip irrigation before crop transplant.
[w]Nontreated controls included both mulched and nonmulched plots.
[v]Data on squash plant response to treatments were combined for 2000 (direct seed and transplant), 2001 (direct seed and transplant), and 2002 transplant; 2002 direct seed squash data were analyzed separately due to differences in plant response to treatments.

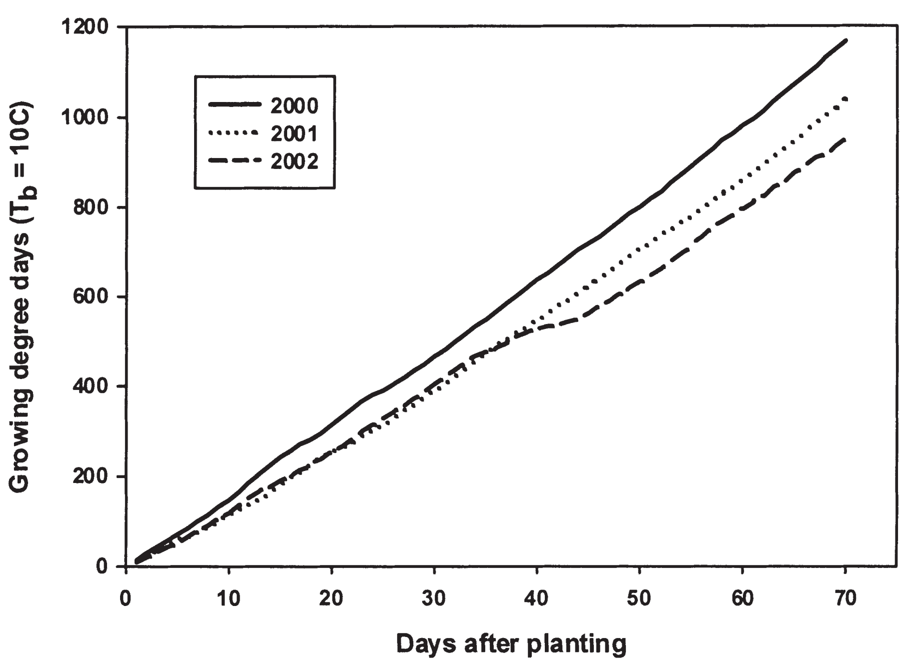

Fig. 1. Growing degree-day (T_{base} = 10 °C) accumulation following squash planting/transplanting in 2000, 2001, and 2002

Table 2. The influence of nutsedge management treatments on zucchini squash yield.

Treatment	Initial harvest	Second harvest	Final harvest	Cumulative yield
Squash yield biomass as % of nontreated control				
Halosulfuron-DRIP[z]	73	119	130	116
Halosulfuron-PRE[y]	62	105	104	102
Metham[x]	148	132	134	141
Mulched nontreated control[w]	100	100	100	100
Nonmulched nontreated control[w]	13	40	49	41
$LSD_{0.05}$	32	31	28	15

[z]Halosulfuron applied at 39 g·ha^{-1} through drip irrigation before crop transplant.
[y]Halosulfuron applied at 39 g·ha^{-1} to the soil surface immediately before laying polyethylene mulch.
[x]Metham applied at 145 kg·ha^{-1} through drip irrigation before crop transplant.
[w]Nontreated controls included both mulched and nonmulched plots.

Table 3. Cucumber yields in mulched plots are relatively insensitive to treatments applied to the previous crop.

Treatment	Initial harvest	Second harvest	Final harvest	Cumulative yield
Cucumber yield biomass as % of nontreated control[v]				
Halosulfuron-DRIP[z]	108	144	115	95
Halosulfuron-PRE[y]	131	134	134	106
Metham[x]	109	159	133	123
Mulched nontreated control[w]	100	100	100	100
Nonmulched nontreated control	76	90	63	73
$LSD_{0.05}$	NS	60	36	21

[z]Halosulfuron applied at 39 g·ha^{-1} through drip irrigation immediately following laying polyethylene mulch.
[y]Halosulfuron applied at 39 g·ha^{-1} to the soil surface immediately before laying polyethylene mulch.
[x]Metham applied at 145 kg·ha^{-1} through drip irrigation immediately following laying polyethylene mulch.
[w]Nontreated controls included both mulched and nonmulched plots.
[v]Due to lack of significant subplot (direct seed vs. transplant cucumber) and sub-subplot (halosulfuron-DRIP vs. nontreated before cucumber planting/transplanting), only main plot treatments (applied before squash) were presented.

ferences in early season crop injury, it was possible to combine yield data across years and planting methods. Due to the similarity in trends among fruit number and fruit biomass in response to main plot treatments, only data on fruit biomass are presented.

Fruit yield from the initial harvest was greater in metham plots relative to all other treatments, a consistent trend throughout the study (Table 2). Halosulfuron-PRE delayed fruit maturity relative to the mulched nontreated control at the initial harvest. Halosulfuron-DRIP was not different than the mulched nontreated control or halosulfuron-PRE at the initial harvest. By the second harvest, there were no differences between halosulfuron treatments and metham or the mulched nontreated control. For the final harvest and cumulative total harvest, all mulched treatments were equivalent or better than the mulched nontreated control. Yield from metham was greater than halosulfuron-PRE at the final harvest and greater than all other treatments in terms of cumulative yield. Halosulfuron-DRIP had a greater yield than the nontreated control in the final harvest and cumulative yield.

In plots without the weed suppressive-benefits of polyethylene mulch (nonmulched nontreated control), squash yields were no greater than 49% of the mulched nontreated control. The competition for resources with crowfootgrass [*Dactyloctenium aegyptium* (L.) Willd.], pink purslane (*Portulaca pilosa* L.) and Florida pusley (*Richardia scabra* L.) in the nonmulched plots were most likely responsible for the differences in crop yield between the nontreated controls (nonmulched vs. mulched). The polyethylene mulch in all other treatments effectively suppressed these weeds.

Early harvests are often critical factors in determining the profitability in fresh market commodities. The utility of halosulfuron in summer squash to control nutsedges may be limited due to the potential for significant crop injury and delay in fruit maturity. However, following the initial harvest, fruit yield from halosulfuron-DRIP treatments were similar to metham and the total cumulative yield was superior to the mulched nontreated control. A complicating factor that may also hinder the use of this treatment is the variability in squash response to halosulfuron across varieties. The variety used in the current test ('Spineless beauty') was among the varieties that possessed intermediate sensitivity to halosulfuron (Webster et al., 2003). Other varieties may be more severely injured, which may affect crop competitiveness, especially where nutsedge populations are high. The current study was conducted in an area with low nutsedge densities to evaluate crop tolerance to halosulfuron. An aggressive squash plant can provide a significant amount of shade and out-compete nutsedge for resources, however a stunted crop may not be as competitive and may suffer greater yield loss than is reported in this study.

Cucumber growth and yield. Unlike squash, cucumber appeared to be relatively tolerant of halosulfuron. Differences in cucumber plant diameter among treatments were not detected (data not shown). There were no differences in cucumber yield among second crop treatments (halosulfuron-DRIP vs. nontreated—split-split plot effects) or planting methods (direct seeded vs. transplanted—split plot effects) (data not shown). There were significant differences among main plot effects (first crop treatments), however this was largely the influence of the nonmulched nontreated control. Cucumber yields in halosulfuron treatments were equivalent to mulched nontreated control (Table 3). The cumulative yield in halosulfuron-DRIP was lower than metham, but equivalent to all other mulched treatments. These data support previous greenhouse and field studies that demonstrated relative safety of halosulfuron to cucumber when applied before planting or transplanting (Mitchem and Monks, 1997; Stall and Majek, 1995; Webster et al., 2003). The aggressiveness of the autumn-planted cucumber relative to the spring-planted squash is demonstrated through higher yields in the nonmulched nontreated control (73% of the mulched nontreated control for cucumber, 41% of the mulched nontreated control for squash).

The option of halosulfuron application through the drip irrigation could be a beneficial means of controlling nutsedge in the second and third crop in existing polyethylene mulched beds. However, the results in the current study are preliminary. Additional research on herbicide application through drip irrigation is warranted, including evaluation of the factors that affect uniformity of application (e.g., herbicide concentration in the irrigation water, duration of irrigation, spacing of emitters, etc.), weed efficacy (especially control of nutsedges as distance on the bed from the drip tape increases), and evaluation of halosulfuron tolerances of different varieties and crops.

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